17th Japan-Slovenia Seminar on Nonlinear Science (online)

21 - 23 March 2022

ORGANIZERS

Yoji Aizawa, Marko Robnik, Akira Shudo and Yoshihiro Yamazaki

Waseda University Tokyo, Tokyo Metropolitan University, Japan

CAMTP - Center for Applied Mathematics and Theoretical Physics
University of Maribor, Slovenia
www.camtp.uni-mb.si

FOREWORD AND INTRODUCTION

Our Japan-Slovenia Seminars on Nonlinear Science have a long tradition and history. It all started in 1989 when Marko Robnik and late Hiroshi Hasegawa, Professor of University of Kyoto, were visiting Institute for Theoretical Physics of the University of California at Santa Barbara, attending the extended (January-June) workshop on Quantum chaos, directed by Professors Martin C. Gutzwiller (IBM, New York) and Eric J. Heller (Harvard University). They started a collaboration in quantum chaos, comprising the hydrogen atom in strong magnetic field (resulting in an extended review article published in Prog. Theor. Phys. Suppl. in 1989), and other works in quantum chaos relating to the Pechukas-Yukawa picture and statistics of energy levels of chaotic systems (published in Europhys. Lett. 1993). Robnik returned to Maribor, Slovenia, in 1989, where he has founded a new research institute CAMTP - Center for Applied Mathematics and Theoretical Physics as a part of the University of Maribor. Hasegawa was regularly visiting CAMTP, and meanwhile moved in 1993 from Kyoto University to Fukui, and later on to Nihon University in Tokyo. In 1993 Robnik was visiting Japan for the first time, thanks to Hasegawa's engagement and hospitality, attending the 5th Yukawa International Seminar "Quantum and chaos: How incompatible?" in Kyoto, organized by the team of Professor Yoji Aizawa et al, headed by Professor Kensuke Ikeda, on 24-28 August 1993. In addition, there was another smaller satellite workshop in Fukui City organized by Hasegawa.

In 1998 Robnik had the honour and pleasure to enjoy a JSPS Fellowship spending two weeks at the Waseda University, Tokyo, hosted by Aizawa, and at the University of Kyoto, hosted by late Professor Hirokazu Fujisaka. It is on this occasion that we decided to cooperate, by organizing Japan-Slovenia Seminar on Nonlinear Science. Our first Seminar, which was embedded in the 4th International Summer School and Conference Let's Face Chaos through Nonlinear Dynamics, was taking place in Maribor in July 1999, organized by Robnik as director of CAMTP. Seven Japanese distinguished professors were attending and some excellent young scientists, PhD students and postdocs from Japan, as well. The former ones were invited speakers and lecturers professors Yoji Aizawa, Hirokazu Fujisaka, Hiroshi Hasegawa, Yoshiki Kuramoto, Mitsugu Matsushita, Katsuhiro Nakamura and Akira Shudo.

After this successful meeting we have been meeting quite regularly 15 more times. In Slovenia this was always in Maribor, organized by Robnik as the director of CAMTP. On one occasion (October 2006) it was Novacella, South Tyrol, Italy, embedded in the European Advanced Studies Conference, organized by Robnik and Dr. Andreas Ruffing from Technical University of Munich, Germany. In Japan, the seminars took place at many different universities hosted by many different professors, on the following list: Waseda University, Tokyo, Yoji Aizawa; Tokyo Metropolitan University, Akira Shudo; Chuo University, Tokyo, Mitsugu Matsushita; University of Tokyo, Kazuo Takatsuka; University of Kyoto, late Hirokazu Fujisaka; Nara Women's University, Mikito Toda; Osaka City University, Katsuhiro Nakamura; Osaka Prefecture University, Hiroaki Daido. At all times we were trying to support and include young researchers, PhD students and postdocs from Japan and from Slovenia, which indeed turned out to be a very inspirational and successful endeavour for both countries. Apart from the Maribor group we always had attendance from University of Ljubljana, in particular Professor Tomaž Prosen with coworkers from the Faculty of Mathematics and Physics, and also a group from the Faculty of Mechanical Engineering. Last but not least, it should be mentioned that our bilateral activity is very much dignified by traditional participation of some invited speakers from third countries, prominent scientists, who appreciate our efforts and deeds.

Thus this year we hold the 17th Japan-Slovenia Seminar on Nonlinear Science, which unfortunately is only online, due to the pandemic conditions. The hosting zoom system is kindly provided by the Tokyo Metropolitan University under the leadership of Akira Shudo. Our scientific program will be very broad and rich, as you can see in this book of abstracts. We do cover practically all physics branches, from fundamental theoretical and experimental physics topics on classical and quantum chaos and complex systems, to applications covered by biophysics, sociophysics, and engineering, and also some nonlinear mathematics. We believe that the meeting will again enrich our scientific life, and will stimulate and support our young researchers. We warmly welcome our three guests from third countries, distinguished Professors Tassos Bountis from University of Patras, Greece, Giulio Casati from University of Insubria, Como, Italy, and Hans-Jürgen Stöckmann from University of Marburg, Germany, who will strengthen our scientific profile.

We thank JSPS - Japan Society for the Promotion of Science for the support of our underlying project "Open Partnership Joint Research Projects/Seminars". The support of ARRS - Slovenian Research Agency under the grant P1-0306 "Applied Mathematics, Theoretical Physics and Intelligent Systems", is gratefully acknowledged.

The organizers:

Yoji Aizawa, Waseda University, Tokyo
Marko Robnik, CAMTP, University of Maribor
Akira Shudo, Tokyo Metropolitan University
Yoshihiro Yamazaki, Waseda University, Tokyo

Maribor and Tokyo, 22 February 2022

SCHEDULE OF TALKS

Monday, 21 March 2022

08:20-08:30(CET), 16:20-16:30(JST)
Marko Robnik
Opening address

Chairman: Tassos Bountis

08:30-09:00(CET), 16:30-17:00(JST)
Yoji Aizawa
Comments on the stagnant motion in nearly integrable Hamiltonian systems
— Nekhoroshev Stability, Log-Weibull law and infinite measure ergodicity —

09:00-09:30(CET), 17:00-17:30(JST)
Takuma Akimoto
Infinite ergodic theory in stochastic models of subrecoil laser cooling

09:30-10:00(CET), 17:30-18:00(JST)
Yuzuru Sato
Stochastic bifurcation in a turbulent swirling flow

(Break - 10 minutes)

Chairman: Tomaž Prosen

10:10-10:40(CET), 18:10-18:40(JST)
Tassos Bountis
Energy transport in 1-D Hamiltonian lattices: From physics to engineering

10:40-11:10(CET), 18:40-19:10(JST)
Tetsuro Konishi
Spontaneous non-uniformity of energy distribution in constrained systems and slow relaxation

11:10-11:40(CET), 19:10-19:40(JST)
Mikito Toda
Synchronization of coupled oscillator models on random networks

(Lunch) — (Dinner)

Chairman: Akira Shudo

12:30-13:00(CET), 20:30-21:00(JST)
Valery Romanovski
Periodic oscillations in some models related to reaction kinetics

13:00-13:30(CET), 21:00-21:30(JST)
Barbara Arcet
Integrability and linearizability of polynomial systems of ordinary differential equations

(Break - 10 minutes)

13:40-14:10(CET), 21:40-22:10(JST)
Kazuyuki Yagasaki
Some recent results on nonintegrability of dynamical systems

14:10-14:40(CET), 22:10-22:40(JST)
Gergö Nemes
On the Borel summability of WKB solutions of certain Schrödinger-type differential equations

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Tuesday 22 March 2022

Chairman: Valery Romanovski

08:30-09:00(CET), 16:30-17:00(JST)
Giulio Casati
Quantum chaos and the correspondence principle

09:00-09:30(CET), 17:00-17:30(JST)
Yoshihiro Yamazaki
Relationship between a tropically discretized model showing Neimark-Sacker bifurcation and its ultradiscretized model

09:30-10:00(CET), 17:30-18:00(JST)
Shousuke Ohmori
Ultradiscrete bifurcations for one dimensional dynamical systems

(Break - 10 minutes)

Chairman: Yoshihiro Yamazaki

10:10-10:40(CET), 18:10-18:40(JST)
Felix Fritzsch
Boundary chaos

10:40-11:10(CET), 18:40-19:10(JST)
Andraž Stožer
Loss of calcium waves and connectivity in human islets in diabetes

11:10-11:40(CET), 19:10-19:40(JST)
Matjaž Perc
Complexity and entropy in digitalized visual arts

(Lunch) — (Dinner)

Chairman: Mikito Toda

12:30-13:00(CET), 20:30-21:00(JST)
Tomaž Prosen
Random matrix spectral fuctuations in quantum lattice systems

13:00-13:30(CET), 21:00-21:30(JST)
Masaki Tezuka
Fock space localization in a perturbed Sachdev-Ye-Kitaev model

(Break - 10 minutes)

13:40-14:10(CET), 21:40-22:10(JST)
Enej Ilievski
Superdiffusion and undular diffusion in integrable models

14:10-14:40(CET), 22:10-22:40(JST)
Žiga Krajnik
Anomalous fluctuations in integrable models

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Wednesday, 23 March 2022

Chairman: Takahisa Harayama

08:00-08:30(CET), 16:00-16:30(JST)
Marko Robnik
Quantum phase space localization in chaotic billiards and other systems

08:30-09:00(CET), 16:30-17:00(JST)
Črt Lozej
Exploring the ergodic hierarchy with quantum triangular billiards

09:00-09:30(CET), 17:00-17:30(JST)
Qian Wang
Statistical properties of the localization measure of chaotic eigenstates in Dicke model

(Break - 10 minutes)

Chairman: Marko Robnik

09:40-10:10(CET), 17:40-18:10(JST)
Hans-Jürgen Stöckmann
A spectral duality in graphs and microwave networks

10:10-10:40(CET), 18:10-18:40(JST)
Jizhou Li
Homoclinic orbit theory in classical and quantum chaos

10:40-11:10(CET), 18:40-19:10(JST)
Takahisa Harayama
Two-dimensional microcavity lasers

11:10-11:40(CET), 19:10-19:40(JST)
Mengyu You
Universal single-mode lasing in fully-chaotic microcavity lasers

(Lunch) — (Dinner)

Chairman: Masaki Tezuka

12:30-13:00(CET), 20:30-21:00(JST)
Mirjam Cvetič
Unification of fundamental forces of nature by modern string theory

13:00-13:30(CET), 21:00-21:30(JST)
Marko Žnidarič
Non-Hermitian phantoms

(Break - 10 minutes)

13:40-14:10(CET), 21:40-22:10(JST)
Sho Sugiura
Floquet-intrinsic many-body scar states in a Rydberg system

14:10-14:40(CET), 22:10-22:40(JST)
Marko Marhl
Mathematical modelling of signalling and metabolic pathways in pancreatic alpha and beta cells

14:40-(CET), 22:40-(JST)
Akira Shudo
Closing remark

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LIST OF INVITED SPEAKERS (31)

Prof.Dr. Yoji Aizawa
Waseda University, Tokyo
aizawa@waseda.jp

Prof.Dr. Takuma Akimoto
Tokyo Univ. of Science
varepsilon.pi@gmail.com

Mag. Barbara Arcet
CAMTP, University of Maribor
barbara.arcet@gmail.com

Prof.Dr. Tassos Bountis
P.G. Demidov Yaroslavl State University, Yaroslavl, Russia
and University of Patras, Greece
tassosbountis@gmail.com

Prof.Dr. Giulio Casati
University of Insubria, Como, Italy
Giulio.Casati@uninsubria.it

Prof. Mirjam Cvetič
CAMTP, University of Maribor
and University of Pennsylvania, Philadelphia, USA
cvetic@physics.upenn.edu

Dr. Felix Fritzsch
FMF, University of Ljubljana
felix.fritzsch@fmf.uni-lj.si

Prof.Dr. Takahisa Harayama
Waseda University, Tokyo
harayama@waseda.jp

Dr. Enej Ilievski
FMF, University of Ljubljana
enej.ilievski@fmf.uni-lj.si

Prof.Dr. Tetsuro Konishi
Chubu University, Aichi
tkonishi@isc.chubu.ac.jp

Mr. Žiga Krajnik
FMF, University of Ljubljana
ziga.krajnik@fmf.uni-lj.si

Dr. Jizhou Li
Tokyo Metropolitan University
jizhouli86@gmail.com

Dr. Črt Lozej
CAMTP, University of Maribor
and MPI for the Physics of Complex Systems, Dresden, Germany
clozej@gmail.com

Prof.Dr. Marko Marhl
PEF, FNM, and MF, University of Maribor
marko.marhl@um.si

Dr. Gergö Nemes
Tokyo Metropolitan University
nemesgery@gmail.com

Prof.Dr. Shousuke Ohmori
Waseda University, Tokyo
42261timemachine@ruri.waseda.jp

Prof.Dr. Matjaž Perc
FNM and CAMTP, University of Maribor
matjaz.perc@gmail.com

Prof.Dr. Tomaž Prosen
FMF, University of Ljubljana
tomaz.prosen@fmf.uni-lj.si

Prof.Dr. Marko Robnik
CAMTP, University of Maribor
Robnik@uni-mb.si

Prof.Dr. Valery Romanovski
CAMTP, FERI and FNM, University of Maribor
valerij.romanovskij@um.si

Prof.Dr. Yuzuru Sato
Hokkaido University, Sapporo
ysato@math.sci.hokudai.ac.jp

Prof.Dr. Hans-Jürgen Stöckmann
University of Marburg, Germany
stoeckmann@physik.uni-marburg.de

Prof.Dr. Andraž Stožer
MF, University of Maribor
andraz.stozer@um.si

Dr. Sho Sugiura
NTT Research Inc., California, USA
sshouu@gmail.com

Prof.Dr. Masaki Tezuka
Kyoto University
tezuka@scphys.kyoto-u.ac.jp

Prof.Dr. Mikito Toda
Nara Women's University
m-toda@gc5.so-net.ne.jp

Dr. Qian Wang
CAMTP, University of Maribor
and Zhejiang Normal University, Jinhua, China
qwang@zjnu.edu.cn

Prof.Dr. Kazuyuki Yagasaki
Kyoto University
yagasaki@amp.i.kyoto-u.ac.jp

Prof.Dr. Yoshihiro Yamazaki
Waseda University, Tokyo
yoshy@waseda.jp

Mr. Mengyu You
Waseda University, Tokyo
mengyuyou@akane.waseda.jp

Prof.Dr. Marko Žnidarič
FMF, University of Ljubljana, *marko.znidaric@fmf.uni-lj.si*

ABSTRACTS OF INVITED TALKS

Comments on the Stagnant Motion in Nearly Integrable Hamiltonian Systems

- Nekhoroshev Stability, Log-Weibull Law and Infinite Measure Ergodicity -

YOJI AIZAWA

Faculty of Science and Engineering, Waseda University
Tokyo, 169-8555, Japan
aizawa@waseda.jp

In nearly integrable Hamiltonian systems, the emergence of extremely slow and stagnant motions is a universal phenomenon, where it seems that the simple ergodicity is not guaranteed and a lot of anomalous scaling appear in long time statistics. The aim of the following considerations is to pursue a possible scenario which enables us to understand the common origin of those anomalies in the light of the Infinite Measure Ergodic(IME) theory, though there still remain many theoretical problems ([1],[2],[3],[4]). We start with revisiting the theory of Nekhoroshev stability [5], and will see that the characteristic time obeys the log-Weibull law ([6],[7],[8]), and that the scaling natures of the slow dynamics are realized in a certain class of one-dimensional IME systems, i.e., so-called log-Weibull maps [1]. Those results suggest that a kind of low dimensional IME sub-manifold is embedded in phase space of the slow dynamics under consideration, of which situation is the same as known in the Hamiltonian model of Mixmaster universe [9], where it is proved that the one-dimensional IME sub-manifold exists in the 6-dimensional phase space and the singular behavior of the model is caused by it.

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Infinite ergodic theory in stochastic models of subrecoil laser cooling

TAKUMA AKIMOTO

Tokyo University of Science, Noda, Chiba 278-8510, Japan
takuma@rs.tus.ac.jp •
https://www.rs.tus.ac.jp/takuma/akimoto-lab/top.html

I will present that infinite ergodic theory, originated from mathematics, has been developed in statistical physics. We consider a non-stationary stochastic model of subrecoil laser cooling, which is a powerful technique to cool atoms beyond recoil limit [1]. In this model, the dynamics of the momentum of an atom are described by a heterogeneous random walk (HRW) [2]. In my talk, I will show the theoretical results for the propagator of the momentum and the ergodic properties using the uniform approximation for the jump distribution of the momentum. This model is called an exponential model. In the exponential model, the formal steady-state distribution for the master equation cannot be normalized. This unnormalized distribution is known as an infinite invariant measure in ergodic theory [4]. In this talk, I will show that the integrability of the observable with respect to the infinite invariant measure plays an important role in discriminating the ergodic properties. A result for an integrable regime is a consequence of Darling-Kac-Aaronson's distributional limit theorem in inifinite ergodic theory [4]. On the other hand, a result for a non-integrable regime paves the way for obtaining a distributional limit theorem for a non-integrable observable in infinite ergodic theory.

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Integrability and linearizability of polynomial systems of ordinary differential equations

BARBARA ARCET

CAMTP - Center for Applied Mathematics and Theoretical Physics
University of Maribor, Mladinska 3, SI-2000 Maribor, Slovenia
barbara.arcet1@guest.um.si • *www.camtp.uni-mb.si*

The problems of integrability and linearizability are important and intensively studied problems in the qualitative theory of ordinary differential equations (ODEs). In the first case the challenge is to determine whether a given n-dimensional system of ODEs admits $n-1$ functionally independent analytic first integrals, while we say that a system is linearizable if there exists an invertible substitution which transforms the system under the consideration into a linear one. The aim of our study is to find integrable and linearizable systems in some given families of polynomial systems. I will present the solutions and the methods we applied to solve the mentioned problems for a few Hamiltonian two-dimensional systems with homogeneous and non-homogeneous nonlinearities and a symmetric three-dimensional quadratic system.

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Energy Transport in 1-D Hamiltonian Lattices: From Physics to Engineering

TASSOS BOUNTIS

Centre of Integrable Systems and Nonlinear Dynamics
P.G. Demidov Yaroslavl State University, Yaroslavl, Russia
tassosbountis@gmail.com • https://thalis.math.upatras.gr/ bountis/

Regular and chaotic dynamics of 1-D Hamiltonian lattices of N interacting particles has been extensively studied for more than 60 years, in view of its important applications to statistical mechanics and solid state physics [1]. Most studies have focused on *analytic* particle interactions, ranging from nearest neighbor to full range, often in the presence of on-site potentials [2]. Energy transport in such systems under periodic driving at one end of the lattice has revealed the important phenomenon of *supratransmission*, see e.g. [2, 3]. In the present lecture, I will first describe an approach from local to global dynamics in these systems as the total energy is increased. Next, I will apply this approach to 1-D Hamiltonian lattices that arise in mechanical engineering applications, such as graphene elasticity, Hollomons law of "work hardening", under viscous or *hysteretic* damping. These involve nearest-neighbor interactions that are: (a) either purely non-analytic, (b) harmonic plus non-analytic or (c) analytic with non-analytic hysteretic damping effects [4, 5]. Finally, I will discuss energy transport in these systems, such as wave packet propagation and supratransmission, under periodic driving that includes additive noise effects [6].

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Quantum Chaos and the Correspondence Principle

GIULIO CASATI

Center for Nonlinear and Complex Systems
University of Insubria, Como, Italy
giulio.casati@uninsubria.it

As remarked by Max Jammer, there was rarely in the history of physics a comprehensive theory which owed so much to one principle as quantum mechanics owed to Bohrs correspondence principle. In this talk we comment on this principle in connection to two important quantities: entanglement and the out-of-time-ordered correlator (OTOC) a diagnostic tool which reduces to the Lyapunov exponent in the classical limit but is well defined for general quantum systems. The correspondence principle requires transition to classical mechanics for all quantities including dynamical chaos. Indeed, one of the main goals in the field of quantum chaos is to establish a correspondence between the dynamics of classical chaotic systems and their quantum counterparts. On the other hand the notion of entanglement is meaningful only in quantum mechanics and its relation to classical chaos is not obvious. In addition, the validity of the correspondence principle has been recently challenged by the observation of an early-time exponential increase of OTOC in classically nonchaotic systems. The role of OTOC as a diagnostic of chaos has also been put in question. Here, we show that the correspondence principle maintains its general validity while OTOC also maintains its role as a diagnostic of chaotic dynamics.

References

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Unification of Fundamental Forces of Nature by Modern String Theory

MIRJAM CVETIČ

Department of Physics and Astronomy and Department of Mathematics
University of Pennsylvania, Philadelphia, PA 19104, USA
and
CAMTP - Center for Applied Mathematics and Theoretical Physics
University of Maribor, Mladinska 3, SI-2000 Maribor, Slovenia
cvetic@physics.upenn.edu

We outline key features of the Standard Model of electromagnetic, strong and weak interactions which is a consistent, experimentally confirmed quantum theory of elementary particle interactions. On the other hand, we point out how gravitational interactions resist a consistent description as quantum interactions with elementary particles.

Subsequently, we focus of key features of String Theory, which is a consistent quantum theory of extended objects - strings, and we elucidate how it unifies quantum theory of elementary particles with quantum gravity. We review how String Theory sheds light on important fundamental questions of theoretical physics such as the quantum structure of black holes, and the geometric origin of quantum particles of the Standard Model. We highlight recent developments in the geometric domain of String Theory where the string coupling constant can be large, i.e. the so-called F-theory. We outline key geometric features of F-theory that have led to a quantum consistent construction of the Standard Model with three families of quarks and leptons, as confirmed by collider experiments. We also highlight subsequent systematic explorations of the landscape of three-family Standard Models as well as future directions for studies of these constructions via machine learning algorithms.

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Boundary Chaos

FELIX FRITZSCH

Physics Department, Faculty of Mathematics and Physics
University of Ljubljana, Jadranska ulica 19, 1000 Ljubljana, Slovenia
felix.fritzsch@fmf.uni-lj.si • *chaos.fmf.uni-lj.si*

Spatiotemporal correlation functions provide the key diagnostic tool for studying spatially extended complex quantum many-body systems. In ergodic systems scrambling causes initially local observables to spread uniformly over the whole available Hilbert space and causes exponential suppression of correlation functions with the spatial size of the system. In this talk, we present a perturbed free quantum circuit model, in which ergodicity is induced by a unitary impurity interaction placed on the system's boundary and that allows for demonstrating the underlying mechanism governing the asymptotic scaling of correlations with system size [1]. This is achieved by mapping dynamical correlation functions of local operators in a system of linear size L at time t to a partition function with complex weights defined on a two-dimensional lattice of smaller size $t/L \times L$ with a helical topology. We evaluate this partition function in terms of suitable transfer matrices. As this drastically reduces the complexity of the computation of correlation functions, we are able to treat system sizes far beyond what is accessible by exact diagonalization. By studying the spectra of transfer matrices numerically and combining our findings with analytical arguments we determine the asymptotic scaling of correlation functions with system size. For impurities that remain unitary under partial transpose, we demonstrate that correlation functions at times proportional to system size L are generically exponentially suppressed with L. In contrast, for generic unitary impurities correlations show persistent revivals with a period given by the system size.

References

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Two-dimensional microcavity lasers

TAKAHISA HARAYAMA

Department of Applied Physics, School of Advanced Science and Engineering
Waseda University, 3-4-1 Okubo, Shinjuku-ku, Tokyo 169-8555, Japan
harayama@waseda.jp

Two-dimensional (2D) microcavity lasers have been studied for the last three decades not only from the viewpoint of novel optical devices but also from the viewpoint of fundamental physics such as PT symmerty, exceptional points, and wave chaos. We will review researches on 2D microcavity lasers emphasizing the relation to the study on quantum chaos.

References

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Superdiffusion and undular diffusion in integrable models

ENEJ ILIEVSKI

Faculty for Mathematics and Physics
University of Ljubljana, Jadranska ulica 19, 1000 Ljubljana, Slovenia
enej.ilievski@fmf.uni-lj.si

I shall discuss various types of anomalous transport properties of integrable many-body systems, particularly in models with nonabelian continuous symmetries featuring superdiffusion and undular diffusion.

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Spontaneous non-uniformity of energy distribution in constrained systems and slow relaxation

TETSURO KONISHI

College of Engineering, Chubu University
1200 Matsumoto-Cho, Kasugai, Kasugai, Aichi 487-8501, JAPAN
tkonishi@isc.chubu.ac.jp

We will discuss equilibrium and dynamical behavior of some constrained systems and related models, namely, multiple pendulum, freely jointed chain, and bead-spring model. First we discuss the non-uniform distribution of average kinetic energy of constrained systems in thermal equilibrium. The models are composed of masses connected with rigid links. The non-uniformity arises from existence of off-diagonal elements of kinetic energy and it is consistent with the generalized principle of equipartition of energy. Typically, excess of average energy is observed in multiple pendulum and freely jointed chain. Next we discuss the dynamical behavior of the model where the right links are replaced by springs. The system relaxes to thermal equilibrium where ordinary equipartition of energy is established and average kinetic energy is uniform over the entire system. When the spring constant is large, the dynamical behavior of the system resembles that of the system with constraints, where the end particles have large average kinetic energy. The relaxation time depends on the spring constant and it is well fitted by the Boltzmann-Jeans type relaxation law $\tau_{relax} \sim A \exp(B\sqrt{k})$.

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Anomalous fluctuations in integrable models

ŽIGA KRAJNIK

Faculty of Mathematics and Physics, University of Ljubljana
Jadranska ulica 19, SI-1000 Ljubljana, Slovenia
ziga.krajnik@fmf.uni-lj.si

We discuss some results on anomalous fluctuations recently observed in the (anisotropic) Landau-Lifhsitz model in equilibrium, a paradigmatic integrable model of interacting classical spins. Typical fluctuations of the time-integrated spin current on sub-ballistic are non-Gaussian and the cumulants are found to grow with different (algebraic) exponents, unlike in the 'standard' scenario of the large deviation theory, where the existence of a scaled cumulant generating functions implies finite scaled cumulants. Similar phenomenology is observed in a simple interacting cellular automaton, where an analytical computation of the full counting statistics is feasible. Asymptotic analysis of the exact solution gives access to the current distribution on all scales and explicit cumulant asymptotics. The scaled cumulant generating function does not generate scaled cumulants. Our findings hint at novel types of dynamical universality classes in deterministic many-body systems.

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Homoclinic orbit theory in classical and quantum chaos

JIZHOU LI

Department of Physics
Tokyo Metropolitan University, Minami-Osawa, Hachioji, Tokyo 192-0364, Japan
jizhouli86@gmail.com

Special subsets of orbits in chaotic systems, such as periodic orbits and homoclinic orbits, can be considered as skeletons upon which the full dynamics of the system is built. In particular, the determination of homoclinic orbits is sufficient for the exact calculation of classical action functions of unstable periodic orbits, which have potential applications in semiclassical trace formulas. In this talk we present a general scheme to determine the classical action functions of unstable periodic orbits in chaotic Hamiltonian systems with homoclinic orbit actions that shadow them in a piece-wise fashion. The results lend themselves to an approximation with controllable exponentially small errors. Furthermore, it does not require an actual construction of the periodic orbit, only its Markov partition sequence. This clearly demonstrates that homoclinic and periodic orbits are equally valid skeletal structures for the tessellation of phase-space dynamics.

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Exploring the ergodic hierarchy with quantum triangular billiards

ČRT LOZEJ

Max Planck Institute for the Physics of Complex Systems
Nöthnitzer Str. 38, D-01187 Dresden, Germany
CAMTP - Center for Applied Mathematics and Theoretical Physics
University of Maribor, Mladinska 3, SI-2000 Maribor, Slovenia
crt@pks.mpg.de

Billiard systems are ideal test-beds for exploring concepts in classical and quantum chaos. In spite of the simplicity of the dynamics, many interesting dynamical regimes may be realized by considering different shapes of the billiard table. The Quantum Chaos or Bohigas-Giannoni-Schmit (BGS) conjecture states that spectra of quantum chaotic systems will exhibit the same statistical properties as random matrices. By contrast, integrable systems are expected to have Poissonian level statistics (Berry-Tabor conjecture). However, many dynamical regimes between chaos and integrability exist and are classically categorized in the ergodic hierarchy. I will present some recent numerical studies of spectral statistics and eigenfunctions of quantum billiards that explore these intermediate regimes with the example of triangular billiards. Due to the straight lines of the boundary, the dynamics in triangular billiards may not be chaotic, and its ergodic properties depend on the number theoretic aspects of the angles. Numerical evidence suggests that generic triangular billiards are strongly-mixing, while generic right-triangles display non-ergodic behaviour. By selecting appropriate angles, we may explore the spectral statistics at different levels of the ergodic hierarchy. I will present strong numerical evidence that confirms the long held belief that the property of strong-mixing is enough to infer random matrix statistics, thereby extending the BGS conjecture.

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Mathematical modelling of signalling and metabolic pathways in pancreatic alpha and beta cells

MARKO MARHL

University of Maribor, Faculty of Education, Faculty of Medicine, and Faculty of Natural Sciences and Mathematics
Marko.Marhl@um.si

Type 2 diabetes mellitus (T2DM) is a burdensome problem of modern society and still puzzles in many aspects of cellular processes leading to this disease and its progression. The problem of dysregulated secretion of glucagon and insulin, the two major hormones produced by pancreatic alpha and beta cells, respectively, that regulate glucose levels in the blood, requires extensive research. Our contribution relates to mathematical modelling of cellular processes in pancreatic alpha and beta cells. We present mechanisms of how mitochondrial dysfunction is associated with impaired glucagon and insulin secretion and consequently with T2DM [1,2]. We also evaluate the influence of metabolically generated cellular energy on the secretion of both hormones [3] and, in addition, the relative importance of cAMP-signalling and metabolic processes on glucagon secretion in alpha cells [4]. The results are further discussed in the context of the relationship between T2DM and metabolic health in general, and COVID-19 [5,6].

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On the Borel summability of WKB solutions of certain Schrödinger-type differential equations

GERGŐ NEMES

Department of Physics, Tokyo Metropolitan University
1-1 Minami-Osawa, Hachioji-shi, Tokyo 192-0397, Japan
nemes.gergo@renyi.hu • www.renyi.hu/∼gergonemes

A class of Schrödinger-type second-order linear differential equations with a large parameter u is considered. Analytic solutions of this type of equations can be described via (divergent) formal series in descending powers of u. These formal series solutions are called the WKB solutions. We show that under mild conditions on the potential function of the equation, the WKB solutions are Borel summable with respect to the parameter u in large, unbounded domains of the independent variable. It is established that the formal series expansions are the asymptotic expansions, uniform with respect to the independent variable, of the Borel re-summed solutions.

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Ultradiscrete Bifurcations for One Dimensional Dynamical Systems

SHOUSUKE OHMORI and YOSHIHIRO YAMAZAKI

Department of Physics
Waseda University, Shinjuku, Tokyo 169-8555, Japan
42261timemachine@ruri.waseda.jp

Recently, applications of the ultradiscretizing method[1] to non-equilibrium dissipative systems such as reaction diffusion systems have been focused on[2,3,4,5,6]. In our presentation, local bifurcations of one dimensional dynamical systems occurring in some ultradiscretizing equations are discussed[6]. The ultradiscrete equations are derived from normal forms of one-dimensional nonlinear differential equations, each of which has saddle-node, transcritical, supercritical, or subcritical pitchfork bifurcations. These bifurcations of the ultradiscrete equations, i.e., the ultradiscre bifurcations, can be characterized with the aid of graphcal analysis. Also, the bifurcation properties between the original normal forms and thier ultradiscrete equations are discussed based on tropical discretization[2]. In particular, the tropically discretized equation obtained from the normal form of supercritical pitchfork bifurcation exhibits the flip bifurcation whose bifrcation parameter is the discretized time interval. Finally, we comment the relationship of the ultradiscrete bifurcations with the border collision bifurcations[7].

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Complexity and entropy in digitalized visual arts

MATJAŽ PERC

Faculty of Natural Sciences and Mathematics,
University of Maribor, Koroška cesta 160, 2000 Maribor, Slovenia
CAMTP - Center for Applied Mathematics and Theoretical Physics,
University of Maribor, Mladinska 3, 2000 Maribor, Slovenia
Complexity Science Hub Vienna,
Josefstädterstraße 39, 1080 Vienna, Austria
matjaz.perc@gmail.com • www.matjazperc.com

The 20th century is often referred to as the century of physics. From x-rays to the semiconductor industry, the human society today would indeed be very different were it not for the progress made in physics laboratories around the world [1]. What the past 100 years have been for science, the past millennium has been for the arts. From the late Byzantine and Islamic art to Renaissance, Realism and Pop art, the past 1000 years are packed with the most productive periods of our creative existence. The availability of digitized visual artworks allows us to perform large-scale quantitative analysis of the history of art. We have analyzed almost 140,000 visual artworks [2], the majority of which were paintings, by more than 2,300 artists created between the years 1031 and 2016. Based on the complexity and entropy of spatial patterns in the artworks, we were able to hierarchically categorize the artworks on a scale of order-disorder and simplicity-complexity, ultimately revealing a clear temporal evolution of the artworks that coincides with the main historical periods of art. Our research indicates a shift in data science, away from semantics towards the quantification of more subjective properties of artworks in general, like aesthetics and beauty [3].

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Random Matrix Spectral Fuctuations in Quantum Lattice Systems

TOMAŽ PROSEN

Faculty of Mathematics and Physics
University of Ljubljana, Jadranska 19, SI-1000 Ljubljana, Slovenia
tomaz.prosen@fmf.uni-lj.si • *chaos.fmf.uni-lj.si*

I will discuss the problem of unreasobable effectivenes of random matrix theory for description of spectral fluctuations in extended quantum lattice systems. A class of interacting spin systems has been recently identified — specifically, the so-called dual unitary circuits — where the spectral form factor is proven to match with circular ensembles of random matrix theory. The key ideas of novel methodology needed in the proofs will be discussed which are very different than the standard periodic-orbit based methods in quantum chaos of few body semiclassical systems.

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Quantum phase space localization in chaotic billiards and other systems

MARKO ROBNIK

CAMTP - Center for Applied Mathematics and Theoretical Physics
University of Maribor, Mladinska 3, SI-2000 Maribor, Slovenia
Robnik@uni-mb.si • www.camtp.uni-mb.si

Quantum localization (or dynamical localization) in systems that are classically chaotic (either ergodic and fully chaotic or partially chaotic, of the mixed-type) is one of the central phenomena in quantum chaos (or wave chaos). The phase space structure of the chaotic eigenstates is studied by means of Wigner functions or Husimi functions. It turns out that they are ergodic (maximally extended in the chaotic part of the phase space) if the Heisenberg time scale of the system with the discrete energy spectrum is larger than the classical transport time scale (for the diffusion in the momentum space), whilst if this condition is not met the chaotic eigenstates are localized in the chaotic part of the phase space. We can quantify the degree of localization by various localization measures, such as the entropy localization measure, the correlation localization measure, or the normalized inverse participation ratio of the Husimi functions. They are all linearly related and thus equivalent. The transition from localized to completely delocalized (ergodic) regime is rather smooth. Also, the spectral statistics is affected strongly by the quantum localization. For example, in fully chaotic systems the level spacings distribution is well described by the Brody distribution, while in the case of the mixed-type systems it is BRB (Berry-Robnik-Brody). The Brody level repulsion parameter goes from 0 in case of the strongest localization (implying Poisson distribution) to 1 in case of complete extendedness on the chaotic component (implying the GOE distribution well approximated by the Wigner distribution for the chaotic part of the energy spectrum). In the extreme special case of ergodic regime with full chaos (no regular component) and no quantum localization the statistics is well described by the Gaussian random matrix theories (GOE). We have shown that the localization measure has a distribution well described by the beta distribution if there are no stickiness regions in the classical chaotic region, and the Brody level repulsion parameter is a linear function of the mean localization measure. I shall explain the general theoretical approach and present the results for the billiard systems while the Dicke system will be presented by Dr. Qian Wang in the next talk. The Dicke system is a mixed-type system with a classical analogue having a smooth potential.

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Periodic oscillations in some models related to reaction kinetics

VALERY ROMANOVSKI

CAMTP - Center for Applied Mathematics and Theoretical Physics
University of Maribor, Mladinska 3, SI-2000 Maribor, Slovenia
Faculty of Electrical Engineering and Computer Science
Faculty of Natural Science and Mathematics
University of Maribor, SI-2000 Maribor, Slovenia
valerij.romanovskij@um.si

We present a computational approach for detecting Hopf bifurcations in polynomial systems of ordinary differential equations depending on parameters. The approach is applied to the investigation of a model related to the double phosphorylation of mitogen-activated protein kinases and a model of tumor growth. For the first model, we analyze the roots of the characteristic polynomials of the Jacobians in the steady state and prove that Hopf bifurcations are absent for biochemically relevant values of parameters. For the second model we show the existence of a Hopf bifurcation.

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Stochastic bifurcation in a turbulent swirling flow

YUZURU SATO

*RIES / Department of Mathematics,
Hokkaido University, Kita 12 Nishi 7, Kita-ku, Sapporo, Hokkaido
060-0812, Japan
ysato@math.sci.hokudai.ac.jp*

We report the experimental evidence of the existence of a random strange attractor in a fully developed turbulent swirling flow. By defining a global observable which tracks the asymmetry in the flux of angular momentum, we reconstruct the associated turbulent attractor modeled by stochastic Duffing equations. A random map extracted from the data exhibits qualitatively same bifurcation as the experiments. Our findings open the way to low-dimensional modeling of systems with large degrees of freedom.

A spectral duality in graphs and microwave networks

HANS-JÜRGEN STÖCKMANN

Fachbereich Physik
Philipps-Universität Marburg, Renthof 5, D-35032 Marburg, Germany
stoeckmann@physik.uni-marburg.de
• *www.uni-marburg.de/fb13/quantenchaos*

Quantum graphs and their experimental counterparts, microwave networks, are ideally suited to study the spectral statistics of chaotic systems. The graph spectrum is obtained from the zeros of a secular determinant derived from energy and charge conservation [1]. Depending on the boundary conditions at the vertices there are Neumann and Dirichlet graphs [2]. The first ones are realized in experiments, since the standard junctions connecting the bonds obey Neumann boundary conditions due to current conservation. On average the corresponding Neumann and Dirichlet eigenvalues alternate as a function of the wave number, with the consequence that the Neumann spectrum is described by random matrix theory only locally, but adopts features of the interlacing Dirichlet spectrum for long-range correlations. Another spectral interlacing is found for the Green function which in contrast to the secular determinant is experimentally accessible. This is illustrated by microwave studies and numerics.

This is a joint work together with Tobias Hofmann, Philipps University of Marburg, and Junjie Lu, Ulrich Kuhl, Université Côte d'Azur of Nice [3].

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Loss of Calcium Waves and Connectivity in Human Islets in Diabetes

MARKO GOSAK, RICHARD YAN-DO, HAOPENG-LIN,
PATRICK E. MACDONALD, ANDRAŽ STOŽER*

**Institute of Physiology, Faculty of Medicine,*
University of Maribor, Taborska ulica 8, SI-2000 Maribor, Slovenia
andraz.stozer@um.si • https://if.mf.um.si/

Islets of Langerhans comprise highly interconnected cells that produce pulses of insulin and other hormones controlling storage and release of energy-rich nutrients. Calcium ions couple stimuli with secretion and coordinate intercellular activity, but both intra- and intercellular coupling are altered in type 2 diabetes mellitus. Most of our knowledge on normal and pathophysiological calcium signaling in islets derives from mouse models and it is not entirely clear whether and how glucose controls calcium oscillations, to what extent they are synchronized in different beta cells, and whether global calcium waves support small-world or some other type of functional network features. Most importantly, it is not entirely clear which of these parameters change in diabetes. To address the above questions, we combined CCD camera-based calcium imaging of isolated human islets with classical physiological and advanced network analyses. In response to glucose, human islets produced regular calcium oscillations that were synchronized in different regions through calcium waves. Higher glucose increased the recruitment of beta cells into an active state, increased the frequency of oscillations, elicited a greater proportion of global waves from more stable initiator regions, and brought about denser and less fragmented functional networks. We observed hub regions with many connections, representing islet domains with the longest active times. Islets from donors with diabetes exhibited a shorter active time, a greater proportion of local waves, less stable initiator regions, and more segregated functional networks. Moreover, hub regions suffered the most by losing a disproportionately large fraction of connections in diabetes. Finally, while some diabetic islets displayed striking pathophysiological changes others from the same donor behaved rather normally, supporting the view that different islets are differently susceptible to diabetogenic insults. Our study is the first to combine classical and network measures in human islets and is able to account for and reconcile practically all of the features observed in previous studies addressing different aspects of calcium signaling. In conceivable future, our approach could be improved by a better temporal and spatial resolution, using additional physiological and pharmacological stimuli, and focusing on islets from patients achieving remission of diabetes, to importantly deepen our pathophysiological understanding of type 2 diabetes, a disease which is becoming a major threat to public health.

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Floquet-intrinsic many-body scar states in a Rydberg system

SHO SUGIURA

NTT Research, Inc.
940 Stewart Drive, Sunnyvale, California 94085, USA
sho.sugiura@ntt-research.com

Thermalization, which is the relaxation to a thermal equilibrium state, is a common phenomenon we encounter in our daily lives. In isolated quantum systems, it was believed that the thermalization still happen as far as the system is chaotic. However, it was recently found in the Rydberg atom system that there are special initial states which will never relax to thermal equilibrium, while other initial states exhibit the thermalization. Such non-thermal states are called many-body scar states.

When the system is periodically modulated with respect to time, this is called a Floquet system. Since the time-modulation excites the quantum state of the system, it was also believed that the quantum state will eventually heat up to infinite temperature in a chaotic system. In this talk, we will show that this expectation is wrong; In some chaotic Floquet systems, we have special quantum states which will not heat up [1]. We use the PXP type interactions without disorder. We rigorously prove the existence of the many-body scar states. Experimental implementation is also proposed.

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Fock space localization in a perturbed Sachdev–Ye–Kitaev model

MASAKI TEZUKA

Department of Physics
Kyoto University
tezuka@scphys.kyoto-u.ac.jp •
http://cond.scphys.kyoto-u.ac.jp/˜tezuka/

We study the physics of many body localization in the Majorana fermion version of the Sachdev–Ye–Kitaev (SYK) model perturbed by a one-body Hamiltonian [1]. Specifically, we consider the statistics of many body wave functions and spectra as the strength of the one-body term is ramped up from an ergodic phase into a (Fock space) Anderson localized phase. Our results [2] are obtained from an effective low energy theory, derived from the microscopic model by matrix integral techniques. The analytical results produced by this formalism are compared to exact diagonalization for systems containing up to 30 Majorana fermions. The statistics of many body spectra and wave functions, and the indicators of the localization are in quantitative agreement with numerics. To the best of our knowledge, this is the first many-body system where a localization transition is observed in parameter-free agreement with first principle analytical calculations. We also obtain the entanglement entropies for the many-body eigenstates and discuss their dependence on the subsystem size and the perturbation strength [3]. Furthermore, we will comment on some sparse variants of the SYK model [4].

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Synchronization of coupled oscillator models on random networks

MIKITO TODA

Nara Women's University, Kita-Uoya-Nishimachi, Nara, 630-8506, Japan
University of Hyogo, Graduate School of Information, 7-1-28 Minatojima-minamimachi, Chuo-ku, Kobe, Hyogo 650-0047, Japan
Hokkaido University, Research Institute for Electronic Science, Kita 20, Nishi 10, Kita-ku, Sapporo, 001-0020, Japan
toda@ki-rin.phys.nara-wu.ac.jp

We will discuss synchronization of the Kuramoto model, the simplest model of coupled oscillators, on various types of random networks. We investigate how the processes of synchronization differ depending on different random networks. The random networks we study are the following three types, Erdös-Rényi(ER), Watts-Strogatz(WS) and Barabási-Albert(BA) models. By introducing a local order parameter, we can successfully differentiate the processes of synchronization taking place in these three models.

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Statistical properties of the localization measure of chaotic eigenstates in Dicke model

QIAN WANG

Department of Physics, Zhejiang Normal University, Jinhua 321004, China
CAMTP - Center for Applied Mathematics and Theoretical Physics University of Maribor, Mladinska 3, SI-2000 Maribor, Slovenia
qwang@zjnu.edu.cn

The quantum localization is one of the remarkable phenomena in the studies of quantum chaos and plays an important role in various contexts. Thus, an understanding of the properties of quantum localization is essential. In spite of much efforts dedicated to the investigating of the manifestations of localization in the time-dependent systems, the features of localization in time-independent systems are still less explored, particularly in quantum systems which correspond to the classical systems with smooth Hamiltonian. In this work, we present such a study for a quantum many-body system, namely the Dicke model. The classical counterpart of the Dicke model is given by a smooth Hamiltonian with two degrees of freedom. We examine the signatures of localization in its chaotic eigenstates. We show that the entropy localization measure, which is defined in terms of the information entropy of Husimi distribution, behaves linearly with the participation number, a measure of the degree of localization of a quantum state. We further demonstrate that the localization measure probability distribution is well described by the beta distribution. We also find that the averaged localization measure is linearly related to the level repulsion exponent, a widely used quantity to characterize the localization in chaotic eigenstates. Our findings extend the previous results in billiards to the quantum many-body system with classical counterpart described by a smooth Hamiltonian, and indicate that the properties of localized chaotic eigenstates are universal.

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Some recent results on nonintegrability of dynamical systems

KAZUYUKI YAGASAKI

Department of Applied Mathematics and Physics
Graduate School of Informatics, Kyoto University
Yoshida-Honmachi, Sakyo-ku, Kyoto 606-8501, Japan
yagasaki@amp.i-kyoto-u.ac.jp •
http://yang.amp.i.kyoto-u.ac.jp/~yagasaki/index_e.html

The problem of nonintegrability is very classical and important in the field of dynamical systems. Its history dates back to the time of Bruns and Poincare in the nineteenth century. In this talk I review my recent results on this topic. First, I describe an outline of the Morales-Ramis theory [1-4] and illustrate the theory for the SEIR epidemic model [5]. Secondly, I explain a theory developed recently for nonintegrability of nearly integrable systems, and briefly describe its applications including the restricted three-body problem and Duffing oscillator [6-10]. The theory is based on the Morales-Ramis theory. Thirdly, I state my very recent result on the nonintegrability of general three- and four-dimensional systems near degenerate equilibria [11]: The Jacobian matrices of the vector fields have a zero and a pair of purely imaginary eigenvalues for the former systems, and have two pairs of purely imaginary eigenvalues without resonance for the latter ones. Finally, I give some comments on future work.

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Relationship between a tropically discretized model showing Neimark-Sacker bifurcation and its ultradiscretized model

YOSHIHIRO YAMAZAKI and SHOUSUKE OHMORI

Department of Physics
Waseda University, Shinjuku, Tokyo, 169-8555, Japan
yoshy@waseda.jp

As an attempt to apply the ultradiscretization method to bifurcation phenomena, we focus on the discrete dynamical system (x_n, y_n) given by the following equation

$$\begin{cases} x_{n+1} &= \dfrac{x_n + \tau(a y_n + x_n^2 y_n)}{1+\tau} \\[2ex] y_{n+1} &= \dfrac{y_n + \tau b}{1 + \tau(a + x_n^2)} \end{cases} \tag{1}$$

Here, a, b, and τ are positive parameters and n is a time step. Equation (1) exhibits the Neimark-Sacker bifurcation, which corresponds to the Hopf bifurcation in continuous dynamical systems, and possesses a limit cycle. In particular, in the limit of $\tau \to 0$, eq. (1) coincides with the Sel'kov model [1]. On the other hand, by performing an ultra-discretization of eq. (1), the following max-plus dynamical system can be obtained under appropriate conditions for τ [2].

$$\begin{cases} X_{n+1} &= Y_n + \max(0, 2X_n) \\ Y_{n+1} &= B - \max(0, 2X_n) \end{cases} \tag{2}$$

Here, B shows the bifurcation parameter. In this presentation, we will show dynamical properties of eqs.(1) and (2) and discuss relationship between them.

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Universal single-mode lasing in fully-chaotic microcavity lasers

MENGYU YOU,[1,*] KOTA MAKINO,[1] DAISUKE SAKAKIBARA,[1] YONOSUKE MORISHITA,[1] SUSUMU SHINOHARA,[1] SATOSHI SUNADA,[2] and TAKAHISA HARAYAMA[1]

[1]*Department of Applied Physics, School of Advanced Science and Engineering, Waseda University, 3-4-1 Okubo, Shinjuku-ku, Tokyo 169-8555, Japan*

[2]*Faculty of Mechanical Engineering, Institute of Science and Engineering, Kanazawa University, Kakuma-machi Kanazawa Ishikawa 920-1192, Japan*

[*]*mengyuyou@akane.waseda.jp*

I shall introduce the study of the universal single-mode lasing in fully-chaotic microcavity lasers. Firstly, I shall briefly introduce the fully-chaotic microcavity lasers and the single-mode lasing conjecture. The numerical results for the lasing states of three different fully-chaotic microcavities and the details of the transition from multimode to single-mode lasing will be shown in the second part, which numerically verified the single-mode lasing conjecture. Then, I would like to present the experimental results of fully-chaotic microlasers, showing that the single-mode lasing state can be achieved under large external pumping power. Finally, I shall discuss the multimode lasing that happened in the experiments and the affection of the environmental temperature to the lasing states.

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Non-Hermitian phantoms

MARKO ŽNIDARIČ

Department of Physics, Faculty of Mathematics and Physics
University of Ljubljana, Ljubljana, Slovenia

A study of random quantum circuits and their average dynamics reveals that the relaxation rate is not necessarily given by the gap of the relevant transfer matrix. Due to non-Hermiticity a many-body explosion of expansion coefficients can happen, resulting in the rate that is either faster, or, even more interestingly, slower than predicted by the largest eigenvalue. This new phenomenon leading to a multistage thermalization of entanglement and OTOC is identified in a number of different random circuits.